TECHNICAL TRIALS WITH WIRELESS IP/ATM ACCESS AT 28 GHZ

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SUMMARY

This document presents results of technical trials and propagation measurements performed by Telia Research AB at 28 GHz. Performance of broadband radio access systems with ATM cell transmission over the air is evaluated. The propagation characteristics are compared to system performance and in clear line-of-sight (LOS) conditions, the transceiver BER performance criterion is fulfilled and no ATM errors detected. With the first system version transmission degradation was observed in heavy rain or multipath, conditions due to trees and buildings. Broadband Internet and file transfer applications to end customers are used in the trial with the second system.

1 INTRODUCTION

Radio access is one of the most promising techniques for a cost-effective introduction of broadband services to end-users, e.g. broadband Internet access and video services. The growing interest in point-to-multipoint (PMP) radio systems is obvious. Broadband radio access systems that will be able to serve users with large bandwidths, typically a peak rate per user of 2 - 25 Mbps, must be allocated in frequency bands, where the system bandwidth is large enough. These bandwidths will probably be available only above 10 GHz.

The main objectives of the technical trials presented in this paper have been to evaluate the "ATM over radio" performance at 28 GHz and to study the related propagation characteristics. The technical trials were based on two versions of a NEC system, described in section 2. The measurement set-up for BER and ATM performance in uplink and downlink, is given in section 3 and results of the measurements are presented in section 4. A conclusion of the trials is given in section 5.

2 TRIAL SYSTEM OVERVIEW

The broadband radio access systems used in the trials have a microwave radio part, an ATM switch part and subscriber terminals, i.e. Customer Premises Equipment (CPE). The system operates in TDM/TDMA mode with frequency division duplex (FDD) and carries ATM cells over the microwave radio between base station (BS) and each user's PC connected with a CPE. Hence, it is possible to access the ATM backbone network through the BS. The first system used in the technical trial (hereafter system I) consists of one BS and two CPE's. A block diagram of this BS is shown in figure1 and the CPE configuration is presented in figure 2. A similar architecture have been used in the second trial system (hereafter system II), where 2 BS sectors and more than 15 CPE's have been used. The system II performance is upgraded and the subscriber configuration is also given in figure 2. In system I, the CPE equipment has an ATM interface board for user PC connection, while the ATM is terminated in the modem terminal in system II and the user PC interface is 10BASE-T.

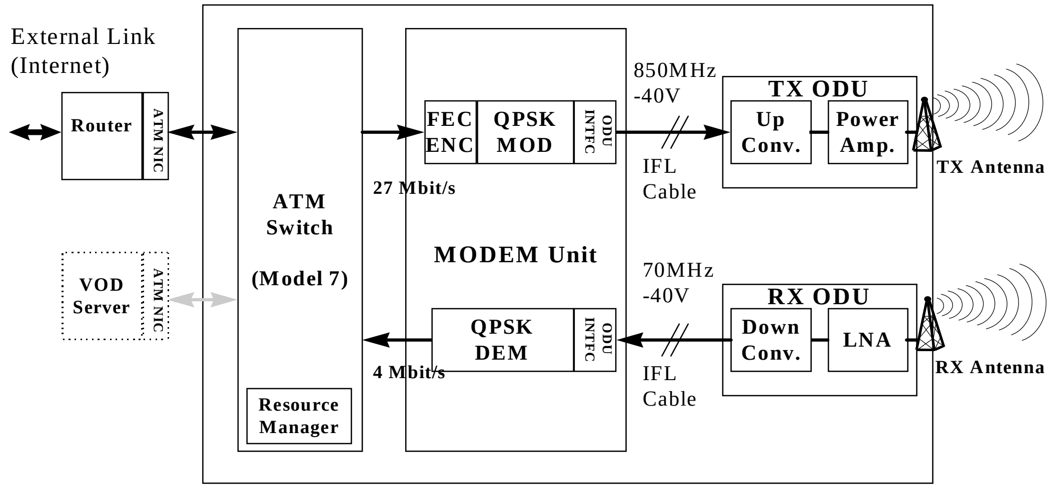

Figure 1. Block diagram of wideband measurement transmitter and receiver.

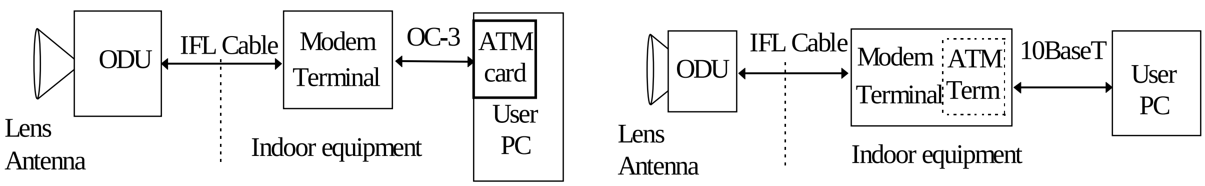

Figure 2. Configuration of CPE in system I (left) and system II (right).

The radio frequency for the downlink (from BS to CPE) is 28 GHz for both systems and the uplink the frequency is 29 GHz and 31 GHz for system I and II, respectively. The transmission rate and modulation in the downlink is 27 Mbps QPSK with roll-off α=0.35. A Reed-Solomon RS(204,188,T=8) FEC is applied to reach the ATM channel requirements. A convolutional outer code with rate 7/8 is also used in system II to reduce the C/(N+I) threshold from 13.5 to 11.0 dB for BER=10^{-10}. The transmission rate for the uplink is 4 Mbps and DQPSK modulation with roll-off α=0.5 and α=0.3, is used in system I and II, respectively. No coding was used in the uplink in system I, while system II used a RS(63,53,5), which reduces the BER=10^{-6} threshold from 19.1 to 17.1 dB

In system I, the BS has 20 dBm RF output level per carrier with an omni directional antenna of 6 dBi gain, while the CPE has 17 dBm output level and a 14 cm lens antenna of 28 dBi nominal gain. Output power and antenna gains are increased in system II, to be able to run services up to a distance of 5 km from the BS. The downlink output power is 22.5 dBm per carrier and the corresponding BS transmitter antenna gain is 12 dBi. The CPE output power is 20 dBm and the antenna gain is 30 dBi, which gives an EIRP of 47 dBm when the 3 dB branching loss is included. Some of the parameters for the power link budget of the downlink and uplink for the two systems are given in table 1. The downlink with system I has 4.7 dB flat fading margin at path length 2.0 km for the given threshold BER=10^{-10}, while the uplink margin is 4.6 dB for BER=10^{-6}. The system margin for 99.9% availability in Scandinavian rain zone, are then 2.0 dB and 1.9 dB for downlink and uplink, respectively. The corresponding margins at 2.0 km distance from the BS are almost 15 dB with system II.

NEC's ATM Switch Model 7 with special hardware (line interface board) and tuned software for the trials is used. The switch located at the BS is equipped with a ATM 155 Mbps STM-

1/OC-3 interface for ATM backbone connection, a ATM 27Mbps interface and ATM 4Mbps interface for radio modem connection at the BS. MAC layer resource management function is also mounted. Key features of the resource manager include assignment of data channel for uplink and downlink to each CPE based on an allocation algorithm, negotiation with Connection Manager of ATM Switch and selection of VPI for the uplink and downlink.

Table 1. Link budget for system I and II.

	Downlink I	Uplink I	Downlink II	Uplink II
Frequency	28 GHz	29 GHz	28 GHz	31 GHz
TX power/Carrier	20 dBm	17 dBm	22.5 dBm	20 dBm
Antennas	6 dBi	28 dBi	12 dBi	30 dBi
EIRP	25.4 dBm	42.0 dBm	33.9 dBm	47.0 dBm
RX power @ 2 km	-77.0 dBm	-80.0 dBm	-66.5 dBm	-69.3 dBm
C/N @ 2 km	18.2 dB	23.9 dB	28.6 dB	34.8 dB
C/N BER Thresh.	13.5 dB	19.1 dB	11.0 dB	17.1 dB
Link Margin	4.7 dB	4.6 dB	17.6 dB	17.7 dB
System Margin	1.9 dB	2.0 dB	14.8 dB	14.7 dB

2.1 MEASUREMENT SCENARIOS AND ENVIRONMENTS

Measurements of the first part of the trial have been made in Malmö, Sweden, with one BS and two CPE’s. The BS was installed on top of a building, where the antennas were placed at the roof, approximately 85 m above ground level. Propagation measurements at 28.5 GHz have also been made with a transmitter at the BS location for comparison with system performance, see [1] and [2]. Both CPE’s were installed 1.4 km away from the BS, see the map in figure 3. One CPE was installed at the roof of a building, approximately 20 m above ground level. From this CPE location there was clear LOS to the BS. The other CPE was consecutively installed in different windows in rooms in the same building, approximately 7 m above ground level. The paths between the BS and the two window locations were classified as obstructed line-of-sight (OLOS), due to trees and rooftops obstructing part of the path.

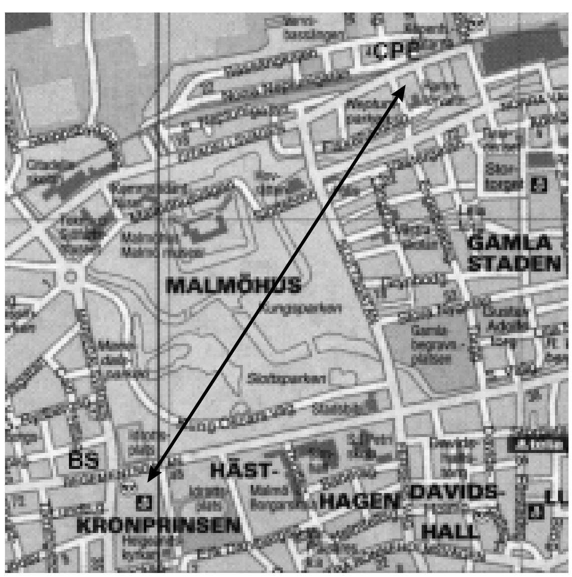

Figure 3. Map of the BS and CPE locations in Malmö, with the separation 1.4 km.

The trial with system II consists of one BS with two ODU's, for coverage of two 90° sectors (pointing north and south). The BS was placed in a tower at a height of approximately 70 m, at Telia premises in Farsta. Measurement results at eight CPE locations up to the coverage range of approximately 5 km within the sectors are presented in this paper. The BS and some of the CPE locations are shown in figure 4.

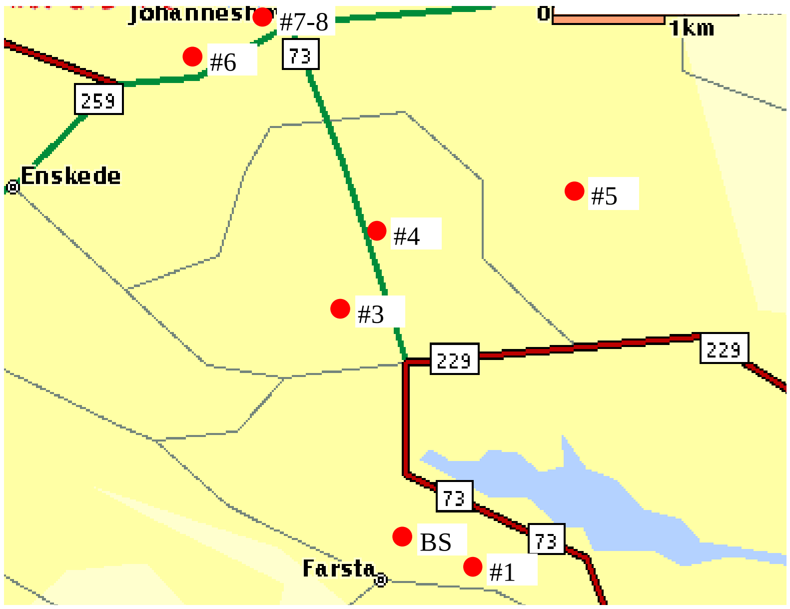

Figure 4. Map of the BS and CPE locations around the Farsta site (#2 is further south).

2.2 POWER, BER AND ATM MEASUREMENT CONFIGURATION

The received power measurements were made by logging AGC output signal levels of the BS and CPE modems. Recordings of the values were made with a sample rate of 50 Hz by laptop PC's and data acquisition cards. For execution of the recordings and control of sampling, Labview software routines have been used. The dynamic range of the AGC is more than 25 dB and this Rx level representation is analogue in the downlink while it is digital in the uplink, since the burst level is latched. The time constant of the AGC implies that the average received power is recorded. Also note that the use of two antennas at the BS and two carrier frequencies for uplink and downlink, implies that the radio channels are not identical.

Using a pattern generator at the transmitter and a corresponding pattern detector at the receiver made BER measurements. For the downlink the pattern generator is clocked at 27.36 MHz. The pattern generator is first fed into a frame generator and then into the BS modem. At the CPE the signal is taken from the modem to the pattern detector via a test jig. A block diagram of the downlink measurement configuration at CPE is shown in figure 5. Uplink BER measurements use the same configuration except that the 27.36 MHz clock signal is not needed due to the lower bit-rate of 4 Mbps. The BER is represented by a voltage, which increases from 0 V without errors to 1.5 V for BER=10^{-7} and 4 V for BER=10^{-2} in 0.5 V steps. In the second part of the trial, i.e. with system II, received downlink power as well as BER have been measured with a similar configuration, while the uplink power was estimated at IF in a spectrum analyzer (which reduced the absolute power accuracy).

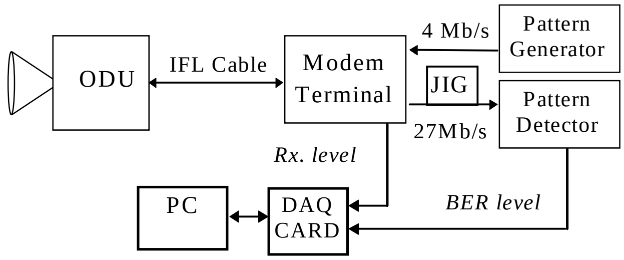

Figure 5. Measurement configuration for received power and BER in the downlink.

The ATM measurements with system I were made with 2 ATM-analyzers (Wandel & Golterman ANT-20), one at the BS and one at the CPE, connected to the OC-3 ports, see figure 6. With a downlink data load of 26.96 Mbps (63579 cells/s) and an uplink data load of 1.80 Mbps (4239 cells/s), we measured cell error ratio (CER), cell loss ratio (CLR) and cell transfer delay/cell delay variation (CTD/CDV) for the different locations. The received power was recorded simultaneously according to the BER measurements, presented above. The CTD/CDV measurements were done at the CPE location only. This was possible by looping the BS ATM-switch. A fully allocated US frame (100 slots) with a data load of 1.8 Mbps was used.

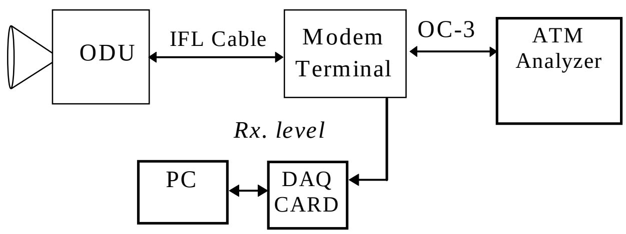

Figure 6. Measurement configuration for received power and ATM quality in the downlink.

3 ANALYSIS AND RESULTS

The main purpose of the first part of the trial, i.e. with system I, was to evaluate the radio related parameters. Hence, uplink and downlink received RF-power, BER and ATM performance was measured at the BS and CPE’s respectively. With system II we have, so far, measured the received power and BER, but also investigated user aspects on the performance.

3.1 TRIAL IN MALMÖ WITH SYSTEM I

The received power and BER voltage was simultaneously measured for downlink (DS) and uplink (US) during 10 minutes with CPE ODU on the roof. A sequence of received DS and US power levels during one minute is given in figure 7. The data show that the variations are very small, i.e. within 1 dB, in this LOS situation. The downlink average power is -71.5 dBm, which is only 2 dB higher than the value calculated using the nominal antenna gains, see link budget table 1. The uplink average power is -78.7 dBm, which in contrary to the downlink is 1.5 dB lower than the calculated value. These small differences are mainly due to variations in the antenna patterns for downlink and uplink. No errors were detected during the 10 minutes recording; i.e. the BER voltage was 0 V, which means that the BER quality criteria of 10^{-10} for downlink and 10^{-6} for uplink were fulfilled. The corresponding system margins are 11.0 dB and 5.6 dB respectively, when the 99.9% rain margin at 1.4 km is taken into account.

The received power and BER voltage for the downlink (DS) and uplink (US) of 5 minutes simultaneous recording with the CPE located 7 m above ground in the left window in a room, are shown in figure 7. The received downlink power is approximately -78 dBm, which is just 4 dB below the calculated level for a clear LOS location, i.e. -73.9 dBm, at 1.4 km separation. The downlink BER level of 10^{-7} is exceeded only once, when the received power was lower than -78 dBm. The noise limited modem performance measured in laboratory shows that the BER=10^{-7} when the power is -85.3 dBm. The difference of approximately 6 dB between these power levels for the given BER, is probably a consequence of ISI at a certain moment at this location. The received power of the uplink is approximately -82 dBm, which is 5 dB below the nominal LOS level, due to obstructions. Thus, the difference between uplink and downlink is only 4 dB. This is very close to the theoretical 3.3 dB, which is valid when the antenna patterns and gains are identical for uplink and downlink frequencies. The only transmission errors occur when the received power is lower than -83 dBm, i.e. BER=10^{-7} for this power level, which indicates that there is no ISI in the uplink due to longer symbol duration.

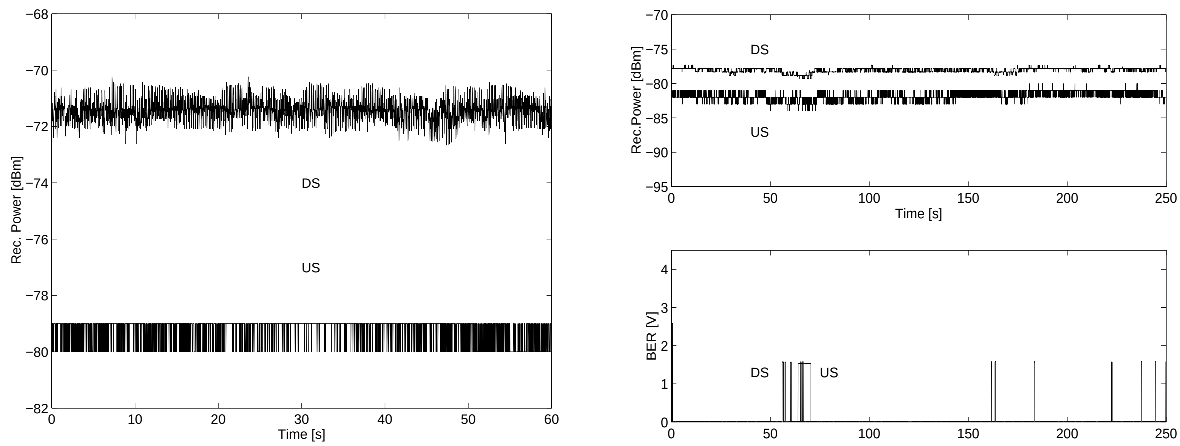

Figure 7. Simultaneously measured downlink and uplink power with CPE ODU on the roof (left) and five minutes of power and BER performance with CPE ODU in a window (right).

The CPE ODU located on the roof was used for an additional measurement of downlink power and BER. This measurement was started during a thunderstorm with heavy rain and the downlink performance of 10 minutes of this recording is shown in figure 8. The rain intensity was not measured but, it is clear that it was much higher than 20 mm/h. The difference between the peak power and highest attenuation during this shower is almost 16 dB. The BER level decreases with increasing power in agreement with a noise limited situation. A few errors occur, i.e. BER>10^{-7}, until the received power is higher than -76 dBm. Note that the received power is only an average since the AGC value is used. Hence, temporal fading due to the rain could give lower instantaneous power levels with errors as a result.

The ATM measurements were done at the same locations as the BER measurements. Results from the CPE on the roof showed that the power levels were according to the BER measurements and without any CER or CLR. In figure 9, a 6-minute measurement done in the left window of a room is presented. Again the power level is the same as for the BER measurement and there are no CER or CLR. Thus, it seems like there is no ISI during the ATM measurement at this specific location. Results with the CPE located in the right window of the same room are also given in figure 9. Here, the received power is down to -86 dBm due to propagation path obstruction by trees. The transmission at this CPE location is noise limited and the CER and CLR values are correlated to the received power. It can also be seen from the measurements there is a ratio of approximately 10^2 between CER and CLR. The delay characteristics; i.e. CTD and CDV, of the round trip were examined. The 2-point CDV_{pp} was 256 µs and the mean CTD for the round trip was 1156.62 µs and the max CTD 1280.00 µs.

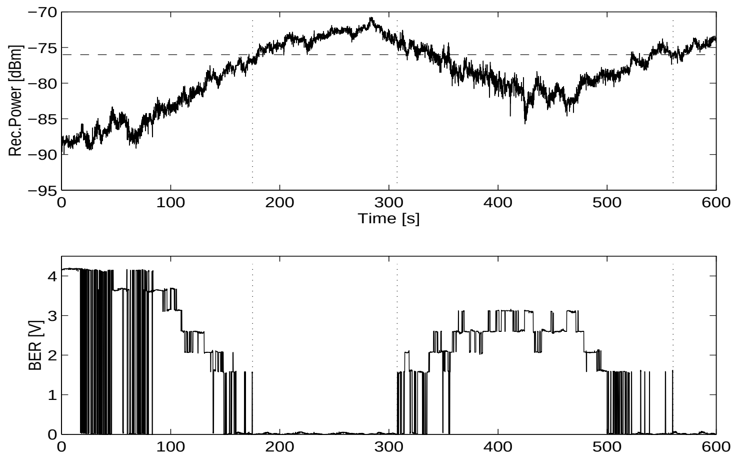

Figure 8. Ten minutes of measured downlink performance during heavy rain showers with CPE ODU on the roof.

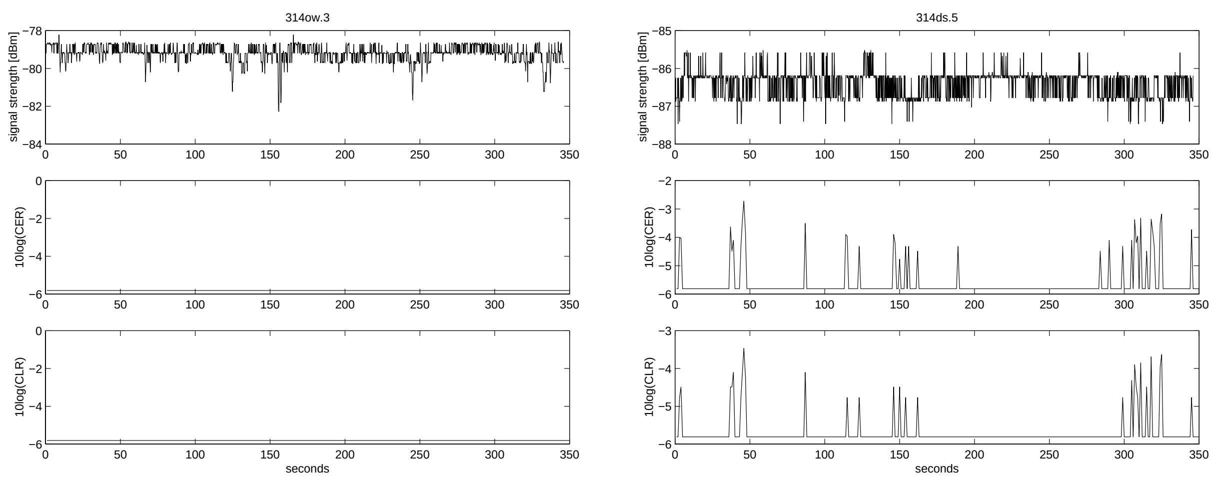

Figure 9. Downlink ATM measurements with CPE in a window, left side almost LOS and on the right side the propagation path is obstructed by trees.

3.2 TRIAL IN FARSTA WITH SYSTEM II

The path loss reltive to the 1m reference of the uplink and downlink measurements with system II are shown in figure 10. Location #1 to #8 in figure 4 refers to the notations from left to right in figure 10. As a reference the free space path loss is plotted in the diagram as well. At one of the locations the propagation path is partly obstructed by trees (#5) and one of the measurements at 5.3 km is made through a window, where extra attenuation reduces the received power. None of these locations showed up any bit errors due to noise or ISI, during several hours of measurements.

At some of the measured locations as well as additional locations in the southern sector trial customers have with satisfaction been using the system for Intranet/Internet browsing and Tele-working, e.g. remote use of normal office applications. The experienced transmission speed of several Mbps per user allows transfer of large data files, which is in practice not possible with voice-band modems or ISDN.

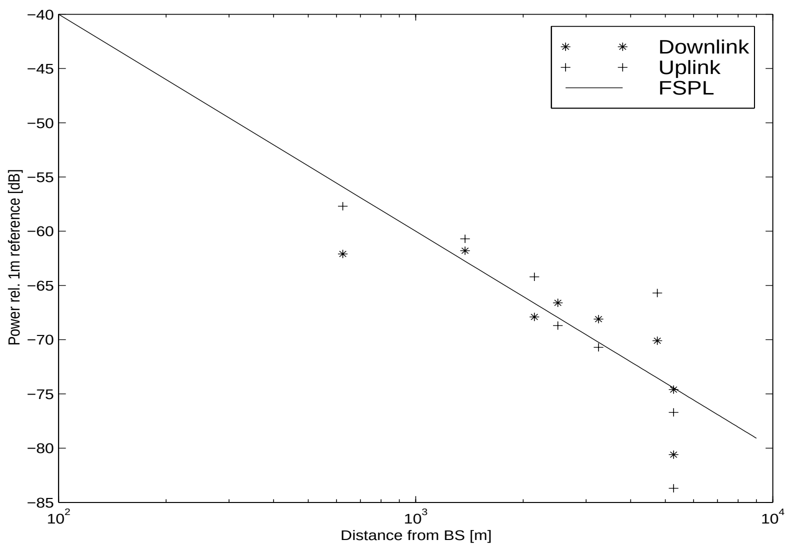

Figure 11. Relative power versus distance from base station for 8 CPE locations in Farsta.

4 CONCLUSIONS

Technical trials of ATM based broadband radio access have been made in Malmö and Farsta, Sweden. Two system versions, including base station with ATM-switch and up to 15 customer premises equipment operating in the 28 GHz-band has been used. The separation between the BS and buildings with the CPEs was in the range 0.6 km to 5.3 km. The simultaneous recorded data files of BER and received power in downlink and uplink have been analysed and we found that the received power levels generally agree with theoretical link budget calculations. The downlink and uplink BER quality is fulfilled when there is clear LOS between BS and CPE. Errors in the downlink have occurred with system I at locations with frequency-selective fading and in heavy rain. Corresponding measurements of ATM performance and received power agree with the BER characteristics, i.e. no cell errors or cell losses were detected in LOS. The radio system also met typical ATM transfer delay and delay variation requirements of an access network. Satisfied residential users are connected to the ATM backbone via broadband radio access for high speed Internet and multimedia services.

ACKNOWLEDGEMENT

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REFERENCES

[1] J. Larsson, ”Narrow-band description of a 28.5 GHz radio channel”, Master Thesis, Dept. Electrical Engineering, Linköping University, nr:LiTH-ISY-EX-1778, 1996.

[2] P. Emanuelsson and P. Karlsson, ”Vågutbredningsmätningar och kanalmodeller i 27-29 GHz bandet”, Proceedings of Radionät, Nordiskt radioseminarium, May 1997.